EXHIBIT 7

DDR5 vs DDR4: Is It Time To Upgrade Your RAM?

By Zhiye Liu published December 19, 2021

Welcome to the new era of DDR5 RAM

Comments (26)

(Image credit: Tom's Hardware)

The arrival of DDR5 opens the door to higher performance levels, but early production pains have led to shortages and scalper-level pricing. That said, DDR5 pricing will eventually fall to something resembling a sane amount, and when that happens, you'll need to determine if it's

worth it to step up to one of the best RAM kits available. But, of course, you also have to determine if there's a big enough performance gain to justify the upgrade.

DDR5 comes with many promises, but one of its most significant selling points is the higher level of bandwidth it can feed to processors with tons of cores. Memory bandwidth has become increasingly important as today's modern chips can reach up to 16 cores for mainstream PCs, but it's common sense that new hardware can struggle compared to hardware that has had enough time to mature. For instance, first-gen DDR4 couldn't compete with the best DDR3 back in the day, and many wonder if history will repeat itself with DDR5.

We'll check out the details below to see the differences in the spec sheets and then dive deep into testing to see where each type of memory is the most effective.

How To Choose The Right RAM

Choosing the right memory for your PC is a very important decision.

PLAY SOUND

DDR5 vs DDR4 Specifications

The DDR5 memory standard promises us a future of denser memory sticks, which ultimately equates to more memory capacity in your system. DDR4 stopped at 16-gigabit memory chips,

but DDR5 can use up to 64-gigabit memory chips. The latter also supports die stacking with up to eight dies on a chip, meaning DDR5 can top out at 2TB per module. That'll be for servers that come with LRDIMMs. DDR5 will probably stop at 128GB per stick in the mainstream market. That density is still far off on the horizon, though, as the initial DDR5 memory modules use 16-gigabit memory chips, so we'll see maximum tamer capacities of 32GB in the near term.

If we look at the JEDEC (Joint Electron Device Engineering Council) specification, DDR4 data rates span from DDR4-1600 up to DDR4-3200. Therefore, it's easy to think of DDR5 as a continuation of DDR4 since DDR5 starts at DDR5-3200 and spans up to DDR5-6400.

However, looking back at the beginning of the DDR4 era, DDR4-1600 memory never became a thing. Instead, DDR4-2133 served as the baseline for DDR4. DDR5 follows a similar pattern. Although JEDEC has specified data rates as low as DDR5-3200, the starting point for many, if not all, mainstream DDR5 products is DDR5-4800.

Unlike the last transition from DDR3 to DDR4, DDR5 doesn't have more pins than its predecessor. Instead, DDR5 retains the arrangement with 288 pins, but the pinouts are different. As a result, the position of the notch has changed and will help prevent less-experienced users from trying to insert a DDR5 memory module into a DDR4 slot, or vice versa. That's only a small change, though. The real game-changer resides at an architectural level that you don't see on the outside of the DIMM.

DDR4 memory modules sport a single 64-bit channel (72-bit if you take ECC into account). In contrast, DDR5 memory modules come equipped with two independent 32-bit channels (40-bit with ECC). JEDEC also doubled the burst length from eight bytes (BL8) to 16 bytes (BL16). The upgrades, as mentioned earlier, improve efficiency and reduce data access latency. On a dual-DIMM setup, this transformation essentially turns DDR5 into a 4 x 32-bit configuration rather than the conventional 2 x 64-bit configuration on DDR4.

To continue the push for better power efficiency, DDR5 features an operating voltage of 1.1V, down from DDR4's 1.2V. However, the only memory kits you'll find at 1.1V conform to JEDEC's timings. For example, the standard operating voltage for DDR4 is 1.2V, but overclocked memory kits or higher-binned memory kits with tighter timings are more demanding on voltage. Just like how we've seen DDR4 scale up to DDR4-5000 at 1.6V, DDR5 will likely climb the voltage ladder as well. It isn't a contest, but 1.35V is the highest DDR5 has gone far (DDR5-6800).

Intel's Extreme Memory Profile (XMP) extension evolves alongside DDR4, so now we have the third iteration of XMP. So, what has changed with XMP 3.0? Well, there are now up to five XMP profiles, and users can modify and save two custom XMP profiles directly onto the SPD.

DDR5 marks a radical change in voltage regulation, too. The motherboard is no longer responsible for voltage regulation because the memory modules have a power management IC (PMIC). (12V on server-grade DIMMs and 5V on mainstream DIMMs.)

The PMIC takes the 5V input from the motherboard and converts it to usable voltages for the voltage rails, comprising of the VDD (1.1V), VDDQ (1.1), and VPP (1.8V). The PMIC helps improve voltage regulation and signal integrity and reduce noise. However, the change is a double-edged sword. The voltage regulator on the DDR5 memory module helps reduce motherboard cost and design complexity but ultimately transfers the cost over to the memory modules. It also makes DDR5 dependent on the supply of PMIC chips, and the ongoing PMIC shortage is the primary reason why DDR5 is in short supply.

In addition to higher bandwidth and improved power consumption, DDR5 will also offer higher capacity per memory module. Memory density and banks go hand-in-hand. When you increase the density, you also have to augment the number of banks to accommodate the extra capacity. DDR5 features a 32-bank structure divided into eight groups. In comparison, DDR4's 16-bank system sports four groups. There are still four banks per group - that didn't change. The increase from 16 to 32 banks enables more pages to be open consecutively. DDR5 also has the Same Bank Refresh function (SBRF), allowing it to refresh one bank per group instead of all banks.

On-die ECC (ODECC) is another one of the critical features of the DDR5 specification, but it shouldn't be confused with standard ECC. Manufacturers turn to smaller nodes to increase the density of the memory chips, and on-die ECC's job is to correct potential errors inside those chips to improve reliability. Unfortunately, the protection is limited to the memory arrays inside the chips — the data is on its own once it moves outside the DIMM. On-die ECC doesn't offer any protection for data in transit, which is why on-die ECC isn't a proper ECC implementation.

One can question on-die ECC's utility since errors are more prominent when the data travels over the memory bus. Furthermore, on-die ECC requires an extra capacity to store parity, representing another added cost to DDR5 (in addition to the PMIC). On-die ECC isn't a replacement for standard ECC, but customers will use both in unison in a server or enterprise environment.

G.Skill Trident Z5 RGB DDR5-6000 C36: Best Of The Best

G.Skill Trident Z5 RGB DDR5-6000 C36 (Image credit: Tom's Hardware)

Intel's 12th Gen Alder Lake processors are the first consumer chips to arrive with DDR5 support. Intel has beat AMD to this one, so we paired the flagship Core i9-12900K processor with G.Skill's Trident Z5 DDR5-6000 32GB (F5-6000U3636E16GX2-TZ5RS) memory kit. It's a dual-channel memory kit with two 16GB DDR5 memory modules with a single-rank design.

By default, the Trident Z5 RGB memory modules operate at DDR4-4800 at 1.1V with JEDEC timings (40-40-40). The XMP 3.0 profile quickly brings the Trident Z5 RGB up to speed for DDR5-6000 with timings configured to 36-36-36-76 and the DRAM voltage at 1.3V. There are faster DDR5 kits, but the Trident Z5 comes with generous overclocking headroom. We didn't have any problems pushing it to higher data rates for our tests.

MSI MAG Z690 Tomahawk WiFi: Brothers From Another Mother

MSI MAG Z690 Tomahawk WiFi (Image credit: Tom's Hardware)

Throughout the DDR evolution, we've seen some manufacturers offer a combination of new and legacy RAM support on some motherboards. In the past, it wasn't unusual to find motherboards that supported both DDR and DDR2. We saw the same trends with DDR2 and DDR3, and even DDR3 and DDR4. However, we don't expect to see a hybrid motherboard for DDR5 due to the voltage regulation's migration over to the DIMM. It's just too complex for both technologies to live in harmony on a single motherboard.

We used MSI's MAG Z690 Tomahawk WiFi motherboard in both DDR4 and DDR5 flavors. They're essentially the same motherboard with different RAM slots, making them directly comparable to each other. It helps us eliminate or reduce the performance delta to a minimum instead of using two different motherboards from different brands or product tiers.

The MAG Z690 Tomahawk WiFi implements MSI's Memory Boost technology, consisting of optimized memory circuits to supply pure data signals. In addition, the DDR4 and DDR5 motherboards bring DDR4-5200 and DDR5-6400 support, respectively, which is more than sufficient for our needs.

Test System and Methodology

To ensure a level playing field, both DDR4 and DDR4 memory modules must operate in a similar configuration with identical density and an equal number of memory ranks.

Modern DDR4 16GB memory modules can feature single-rank (1Rx8), or dual-rank (2Rx8) designs with 16-gigabit and 8-gigabit ICs, respectively. DDR5 16GB memory modules, on the contrary, only come in a single-rank layout with 16-gigabit chips. Therefore, we compared the single-rank 32GB (2x16GB) DDR5 memory with an equivalent single-rank 32GB (2x16GB) DDR4 memory kit for an apples-to-apples comparison.

On the DDR4 end, we used Crucial's Ballistix Max RGB DDR4-4000 32GB (2x16GB) memory kit with two 16GB single-rank DDR4 memory modules, so there's no better point of comparison. The Ballistix Max RGB memory modules are suitable for DDR4-4000 at 1.35V and 18-19-19-39 timings.

DDR5 vs DDR4 (Image credit: Tom's Hardware)

Test System

Processor	Intel Core i9-12900K
Motherboard	MSI MAG Z690 Tomahawk WiFi, MSI MAG Z690 Tomahawk WiFi DDR4
Memory	G.Skill Trident Z5 RGB DDR5-6000 C36 2x16GB, Crucial Ballistix Max RGB DDR4-4000 2x16GB
Storage	Crucial MX500 500GB, 2TB
CPU Cooler	MSI MAG CoreLiquid K360
Graphics Card	MSI GeForce RTX 2080 Ti Gaming X Trio
Power Supply	Corsair RM650x 650W
Case	Streacom BC1
Operating System	Windows 11 Professional
Display Driver	Nvidia GeForce Game Ready 496.76 WHQL

We tested different standard data rates, including DDR4-2133, DDR4-3200, and DDR5-4800 at JEDEC timings. As you know, JEDEC utilizes three separate bins for each data rate (A, B, and C). For our tests, we chose the middle ground. That would be 15-15-15 for DDR4-2133, 22-22-22 for DDR4-3200, and 40-40-40 for DDR5-4800.

Additionally, we evaluated data rates with the tightest timings possible to compare early DDR5 versus some of the best DDR4. Do note that the Ballistix memory kit uses Micron ICs, so we couldn't get the timings as low as we would like. The Trident Z5 RGB memory kit, which uses Samsung ICs, hits the best timings possible for each data rate. It offers a good representation of the pinnacle of DDR5 performance at the moment.

As usual, we manually configured each data rate and its corresponding primary timings. The motherboard took care of the secondary and tertiary timings. Alder Lake officially supports up to DDR4-3200 on Gear 1. However, our sample could hit DDR4-4000 in Gear 1. DDR5, on the other hand, defaults to Gear 2, translating to higher latency. It's foul, but that's the way Intel designed Alder Lake.

All About The Bandwidth

Image 1 of 2

DDR5 vs. DDR4 (Image credit: Tom's Hardware)

Compared to the baseline, DDR5-4800 C40 delivered 112% more bandwidth than DDR4-2133 C15 and 46% more than DDR4-3200 C22. Against DDR4-4000 C16, there was a 19% margin in

favor of DDR5-4800 C40. DDR5-6400 C36 is the best configuration out of the lot — it was just 26.43 GBps shy of hitting the 100 GBps mark in Sandra 2021.

While bandwidth has improved tremendously with DDR5, latency has gotten worse. That's within expectations because DDR5 has looser timings. Even run-of-the-mill DDR4-2133 C15 was 5% faster than DDR5-4800 C40. The margin jumped to 17% with DDR4-3200 C22.

We had to dial the transfer rate up to DDR5-6400 C36 to get on par with DDR4-3200 C22 in terms of latency. Meanwhile, DDR4-4000 C16 was 13% faster than DDR4-6400 C36.

DDR5 Performance

Image 1 of 13

DDR5 vs. DDR4 (Image credit: Tom's Hardware)

In our overall performance measurement, DDR5-4800 C40 was 19% and 14% faster than DDR4-2133 C15 and DDR4-3200 C22, respectively. However, the performance delta decreased when we compared it to performance DDR4. DDR5-4800 C40 was only 9% faster than DDR4-3200 C15. When we went up to DDR4-4000 C16, DDR5-4800 C40's advantage dropped to 5%.

If we look at the best, DDR5-6400 C36 was 11% faster than DDR4-4000 C16. So naturally, you can minimize the difference even more if you use DDR4-4000 C14. But, unfortunately, our Ballistix memory kit was not up to the task.

Predictably, not every type of workload will benefit from DDR5's higher bandwidth. Take your everyday tasks with Microsoft Office, for instance. The delta between the best (DDR5-6000 C36) and the worst (DDR4-2133 C15) was only 4%.

The performance benefits vary even in more specialized workloads. For example, we compared the fastest DDR4 and DDR5 memory kits in Adobe Lightroom (DDR4-4000 C16 vs. DDR5-6400 C36) and found that DDR5 is 28% faster, but the gains in Adobe Photoshop (DDR4-3200 C15 vs. DDR5-6400 C36) and Adobe Premiere (DDR4-3600 C16 vs. DDR5-5600 C36) were less than 1% and 3%, respectively.

Compression jobs will cash in on DDR5. DDR5-4800 C40 was 46% faster than DDR4-4000 C16. However, higher data rates didn't exhibit the same performance gains. For example, DDR5-6400 C36 was 14% faster than DDR5-4800 C40.

DDR5 also excelled in y-cruncher— DDR5-6400 C36 finished the calculations 25% faster than DDR4-4000 C16.

DDR5 Gaming Performance

Image 1 of 8

DDR5 vs. DDR4 (Image credit: Tom's Hardware)

Modern processors and memory are more than sufficient for gaming, and the graphics card is the bottleneck in most cases. The DDR5 results clearly showed that. The performance difference in gaming between the two extremes (DDR4-2133 C15 and DDR5-6400 C36) was only around 8%. However, once we stepped up to something better, like DDR4-3200 C15, DDR5-6400 C36 was only 2% faster.

Focusing on the best DDR4 and DDR5 performance, we saw a 3% difference in *Assassin's Creed Valhalla*, 2% in *Far Cry 6*, *Tom Clancy's Ghost Recon Breakpoint*, *Watch Dogs: Legion*, and *Borderlands 3,* and a 1% delta in *Shadow of the Tomb Raider* and *Wolfenstein: Youngblood*.

Our Key Takeaways

- **DDR5 is fast, but only in some workloads.** On the one hand, our tests revealed that specific tasks benefitted substantially from DDR5, and you can expect double-figure performance gains. However, some workloads were indifferent to DDR5 or showed a minimal performance improvement. Therefore, you should identify the type of workloads that you use on your system and decide whether DDR5 is worth the investment.

- **Don't buy DDR5 for gaming.** The performance uplift is there, but it doesn't warrant an upgrade. Yes, DDR5 helps improve your frame rates, but you also need to keep your expectations in check. So unless you're a hardcore gamer that doesn't like knowing you're leaving performance on the table, you shouldn't pick up DDR5.

- **For now, DDR4 offers more bang for your buck because DDR5 is either out of stock or extremely expensive.** For comparison, the cheapest DDR5-4800 32GB C40 memory kit retails for $273.99, whereas a DDR4-3600 32GB C16 memory kit goes for as low as $137.99. While the former offers 6% higher performance, it's also 99% more expensive than the latter. DDR5 pricing won't remain this high forever, but DDR5 can't compete with the value of high-end DDR4 until it improves.

- **DDR5 has more future-proofing value.** However, manufacturers haven't rung DDR4's death knell. It's undeniable that the next generations of processors will eventually drop DDR4 support. Upgrading to a DDR5 memory kit today means you can reuse it for future platforms. The downside is that DDR5 is still wet behind the ears, so there will be better offerings down the line.

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Zhiye Liu
RAM Reviewer and News Editor

Zhiye Liu is a Freelance News Writer at Tom's Hardware US. Although he loves everything that's hardware, he has a soft spot for CPUs, GPUs, and RAM.

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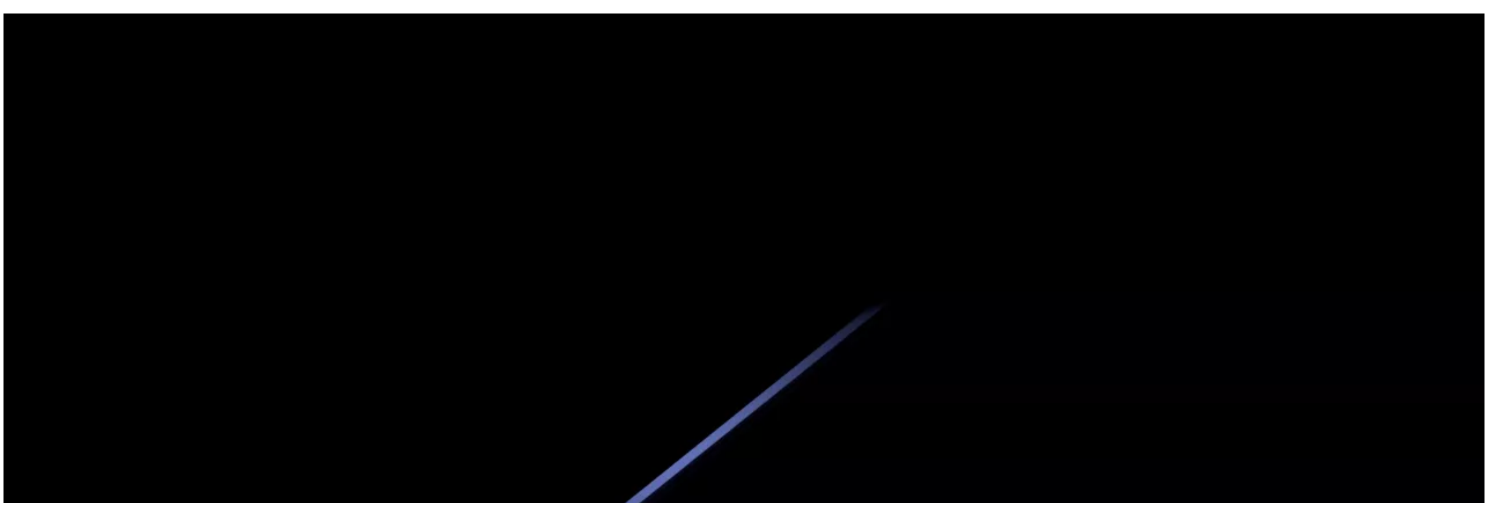

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